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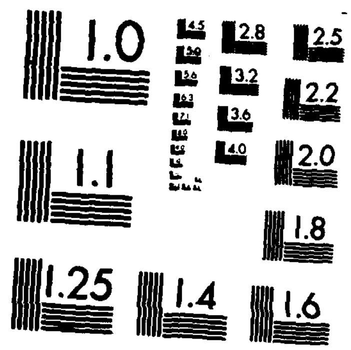

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Interfacial Structure of In/Pt/GaAs Heterojunction Ohmic Contacts

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Graded heterojunction InGaAs ohmic contacts to n-GaAs have been prepared which show improved electrical and morphological properties compared with other diffused contacts. The improvements result primarily from the use of a thin (400 A) Pt layer between the 4000-A In layer and the substrate to control the reaction of the In and the GaAs. A study of chemically etched samples using energy dispersive x-ray (EDX) analysis has revealed the formation of a smooth $In_xGa_{1-x}As$ heterojunction interface.

$In(x), Ga(1-x) As$

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PREFACE

We are grateful to Mr. Paul Adams for the x-ray analyses presented here.

CONTENTS

FIGURES

I. INTRODUCTION

The increasing number and variety of novel electronic devices that use III-V compounds has led to renewed interest in the formation of ohmic contacts to these materials. Although the Ni/Au-Ge contact to n-GaAs has been adequate for the limited number of commercial devices, additional requirements will be imposed by high mobility and graded-gap structures. These requirements include minimizing the contact resistance, the lattice mismatch, and the depth of diffusion into the device structure. Such a need presently exists with respect to ohmic contacts in microwave-power GaAs FETs.

The power dissipated in modestly resistive ohmic contacts can lead to parasitic losses and premature device failure. The standard heavily doped Ni/Au-Ge contacts are known to be highly nonuniform,[1] and have resistivities on the order of 10^{-5} ohm cm^2. An alternative that has been investigated is the use of an InGaAs-graded heterojunction, deposited by molecular beam epitaxy (MBE)[2] or thermal diffusion[3,4] of In metal. These contacts are ohmic by virtue of the formation of a graded $In_xGa_{1-x}As$ heterojunction instead of the usual n^{++}-doped interface region. It is possible to form an In-graded GaAs heterojunction because In forms the entire range of (InGa)As ternary compounds.

An In-based ohmic contact consists of two parts. The first is a graded heterojunction ohmic contact between InAs and GaAs. The second is a direct ohmic contact between InAs and a metal, which forms because the Fermi level at this interface is pinned near the InAs conduction band. The diffused contacts reported by Lahkani[2] were formed by simple annealing of evaporated In overlayers on (100) and (111) n-GaAs and had resistivities on the order of 1×10^{-5} ohm cm^2. It was pointed out that the contacts produced by In diffusion were nonuniform, with the heterojunction forming only in isolated regions on the contact surface. This nonuniformity was believed to be responsible for contact resistivities higher than those reported[2] for MBE-grown InGaAs heterojunctions ($R_c = 10^{-6}$ ohm cm^2). In addition, Lakhani suggested that the heterojunction growth may be epitaxial.

We have previously reported[4] the design, fabrication, and characterization of ohmic contacts consisting of In on (100) n-GaAs with a thin intervening layer of Pt. The Pt layer serves to moderate the reaction of the In and GaAs, producing a more uniform contact with a substantially lower contact resistivity. The electrical measurements presented indicate R_c on the order of 2×10^{-6} ohm cm^2. The experimental procedures were described and ion microprobe mass analysis (IMMA) depth profiles were presented. These IMMA profiles support the hypothesis that the regrowth that occurs during annealing leads to heterojunction formation. In this report we present the results of a scanning electron microscope (SEM)/energy dispersive x-ray (EDX) study on chemically etched samples, which show that the heterojunction is uniform across the contact interface, in contrast to the situation with other diffused contacts. Low-angle x-ray diffraction spectra are also presented here, which confirm the formation of crystalline InAs and indicate that the InGaAs heterojunction is truly epitaxial on GaAs (100).

II. EXPERIMENTAL PROCEDURE AND RESULTS

Evidence for the formation of crystalline InAs was first obtained from the low-angle x-ray diffraction spectrum shown in Fig. 1. The most prominent peaks are due to GaAs (400) and (200) reflections. The corresponding reflections from InAs (400) and (200) are clearly shown, and the relative intensities are consistent with literature data.[5] The widths of the GaAs and InAs peaks are comparable, indicating that the graded region is relatively narrow and that a significant amount of pure, single-crystal InAs has formed at the interface. This is in contrast to the thicker graded regions previously reported,[3] where essentially no pure InAs was observed. Also, the x-ray technique indicates the formation of true crystalline InAs, as opposed to Auger electron spectroscopy (AES) and EDX data, which simply show the coincident occurrence of In and As in the sample.

Other strong signals are due to In_7Pt_3, which is expected to form in a reaction between the excess In and the Pt. The presence of the Pt serves several purposes: (1) Pt allows the In, which becomes molten during the 500°C anneal process, to wet the contact surface and thus form a more uniform contact; (2) Pt is electrically inactive in GaAs, so it does not affect the heterojunction operation; (3) In_7Pt_3 is much more durable, both mechanically and thermally, than the soft In metal, and is therefore more suitable for probing and wire bonding; and (4) Pt reacts strongly with As, and therefore enhances the out-diffusion of Ga.

Additional information on the contact morphology has been obtained by graded etching with Br/methanol in a custom flow system. The SEM image of an etched In/Pt contact is shown in Fig. 2. The unetched metallization on the left (labeled "1") is the In_7Pt_3 alloy with some excess Ga present at the surface. Region 2 contains partially etched metal, which appears as small crystallites. Region 3 has been etched through to the underlying GaAs substrate. EDX analyses taken in Region 2 are given in Fig. 3. Figure 3a shows the composition of a typical crystallite, which is a mixture of the In_7Pt_3 alloy and perhaps a small amount of excess In. The data for Fig. 3b were

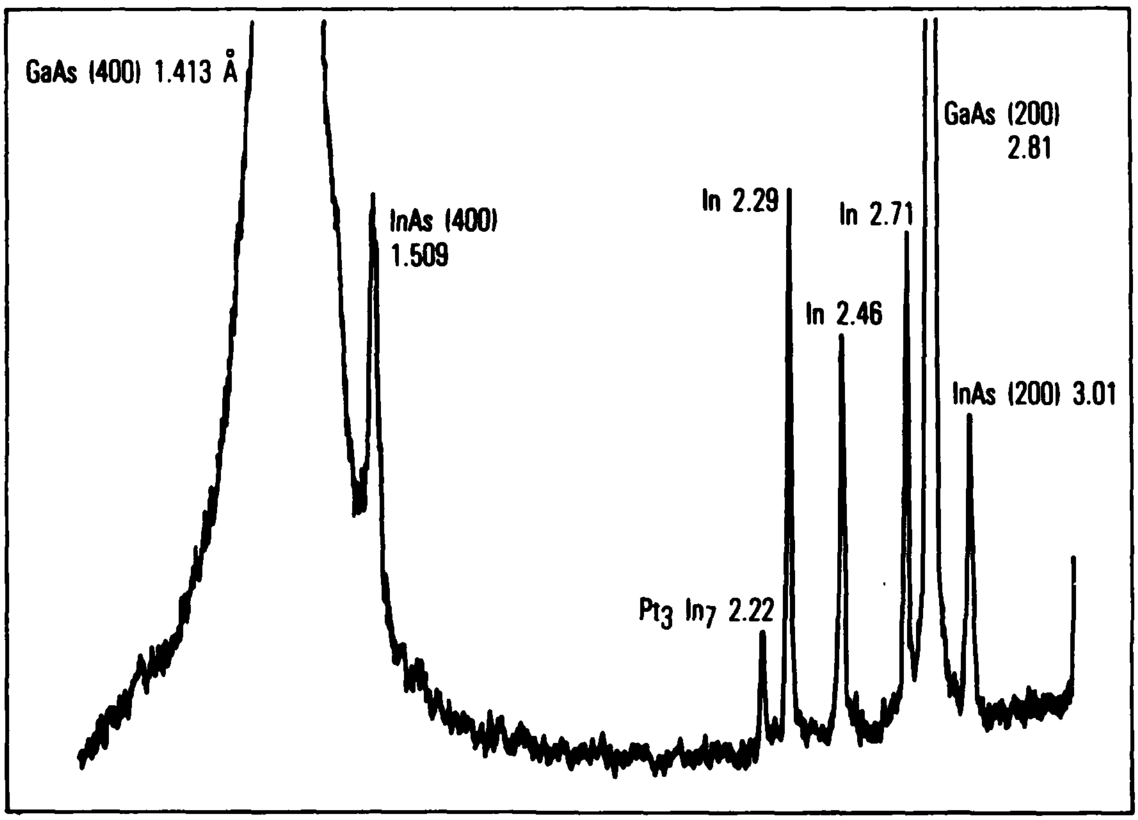

Fig. 1. Low-Angle X-Ray Diffraction Spectrum of Annealed Contact, with Peak Assignments Shown

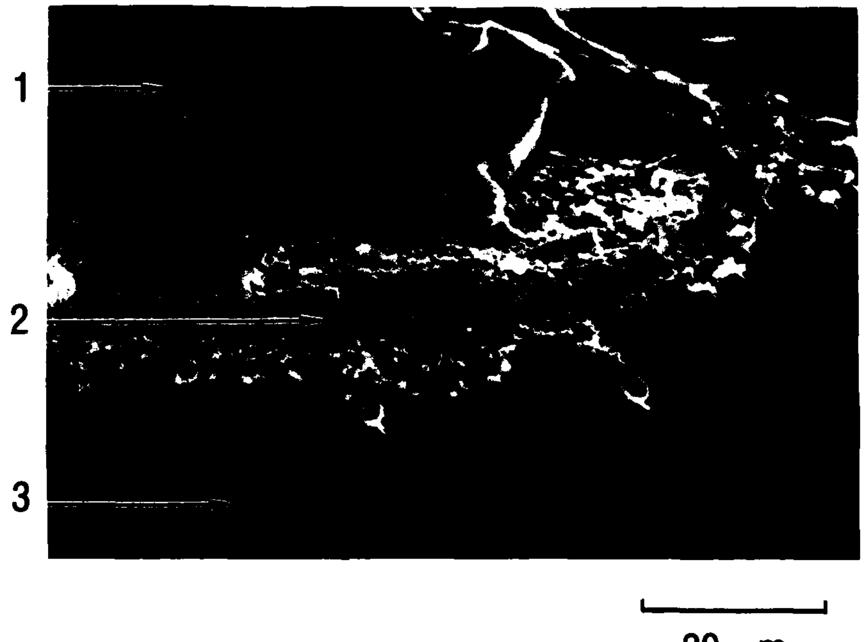

Fig. 2. View of Etched In/Pt Contact

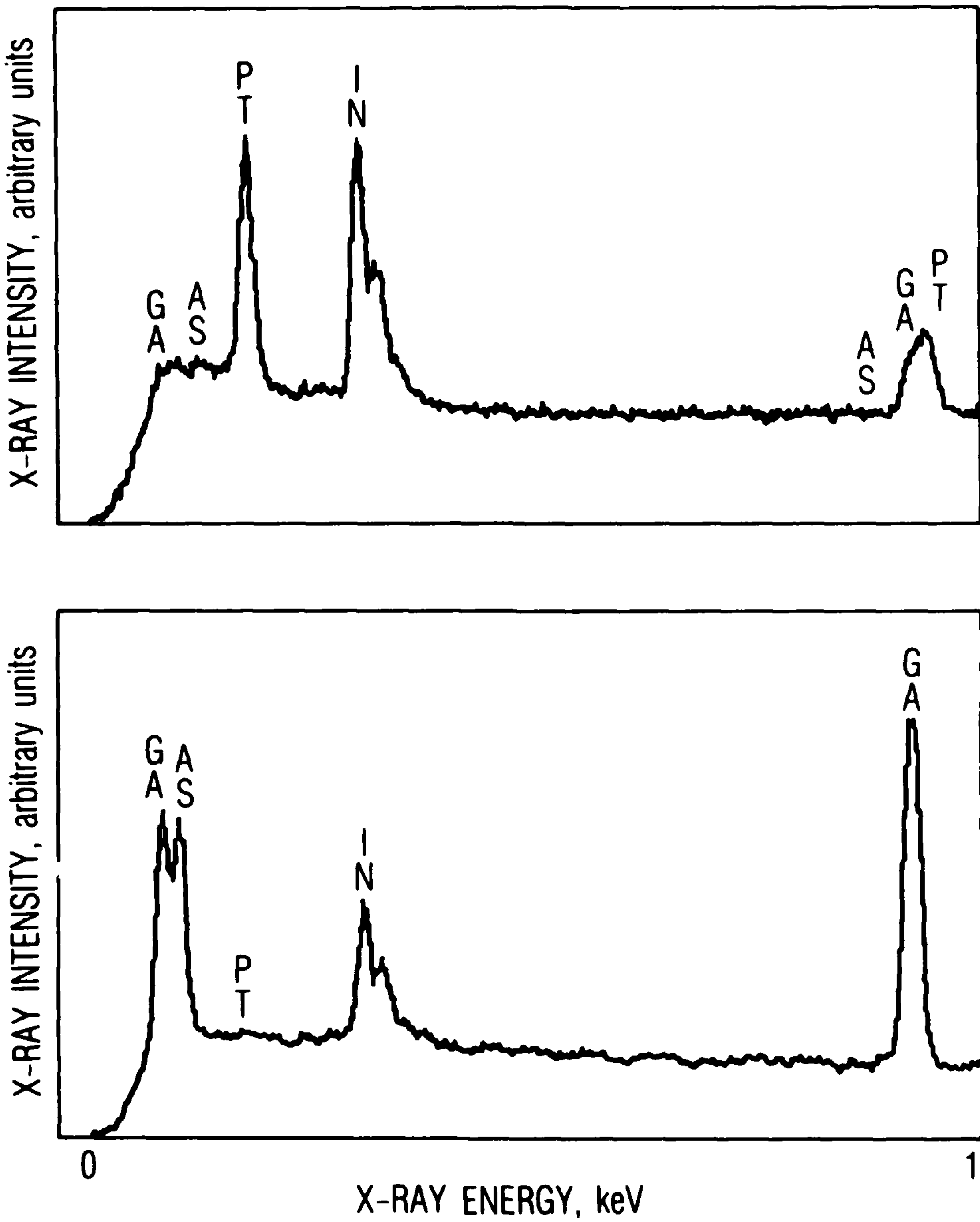

Fig. 3. Energy Dispersive X-Ray (EDX) Spectra of Region 2 in Fig. 2. (a) Crystallite; (b) Flat Area between Crystallites

taken in the flat region between the crystallites, and show a mixture of In, Ga, and As. These regions appear to be the origins of the InAs signals observed in the x-ray data.

A detailed EDX study of these flat regions was performed in order to quantify the relationship between the In, Ga, and As concentrations. This was achieved by obtaining spectra using 10, 20, and 30-kV incident electrons in the EDX analysis. The resulting signal intensities for these elements were then corrected for two effects. The signals for all elements were normalized with respect to the incident electron current, which varied from 9 pA at 10 kV to 85 pA at 30 kV. Second, on the basis of the response variation of a single-crystal InAs sample excited at these three energies, the In and As signals are corrected for their dependence on incident electron energy. The Ga signals were corrected for this dependence by using results from a single-crystal GaAs sample. This procedure provides an easy method for making first-order corrections of matrix effects.

Figure 4 shows an SEM photograph of a typical region from which spectra were obtained. Although the viewing angle in the figure is 55 deg, in order to show clearly the flat areas that occur between the metal crystals during the graded etching procedure, all EDX results were obtained by using electrons at normal incidence. Figure 5 shows the results of the In, Ga, and As analyses. Rather than using electron energy as the independent variable, we converted these values to sampling depths on the basis of the critical excitation energy of In and the density of InAs. The three curves show the intensities of the elemental signals. The As signals are normalized only with respect to the response of pure InAs samples as described. The In and Ga signals are further normalized so that they sum to unity, although the magnitude of this correction was less than 20%.

It is apparent that the amounts of In and Ga present bear an inverse relationship to one another, as required in a ternary material such as $In_xGa_{1-x}As$. Furthermore, the amount of As is observed to remain essentially constant. The dependence of the composition on sampling depth indicates that an $In_xGa_{1-x}As$ heterojunction approximately 1 μm thick is present in the flat

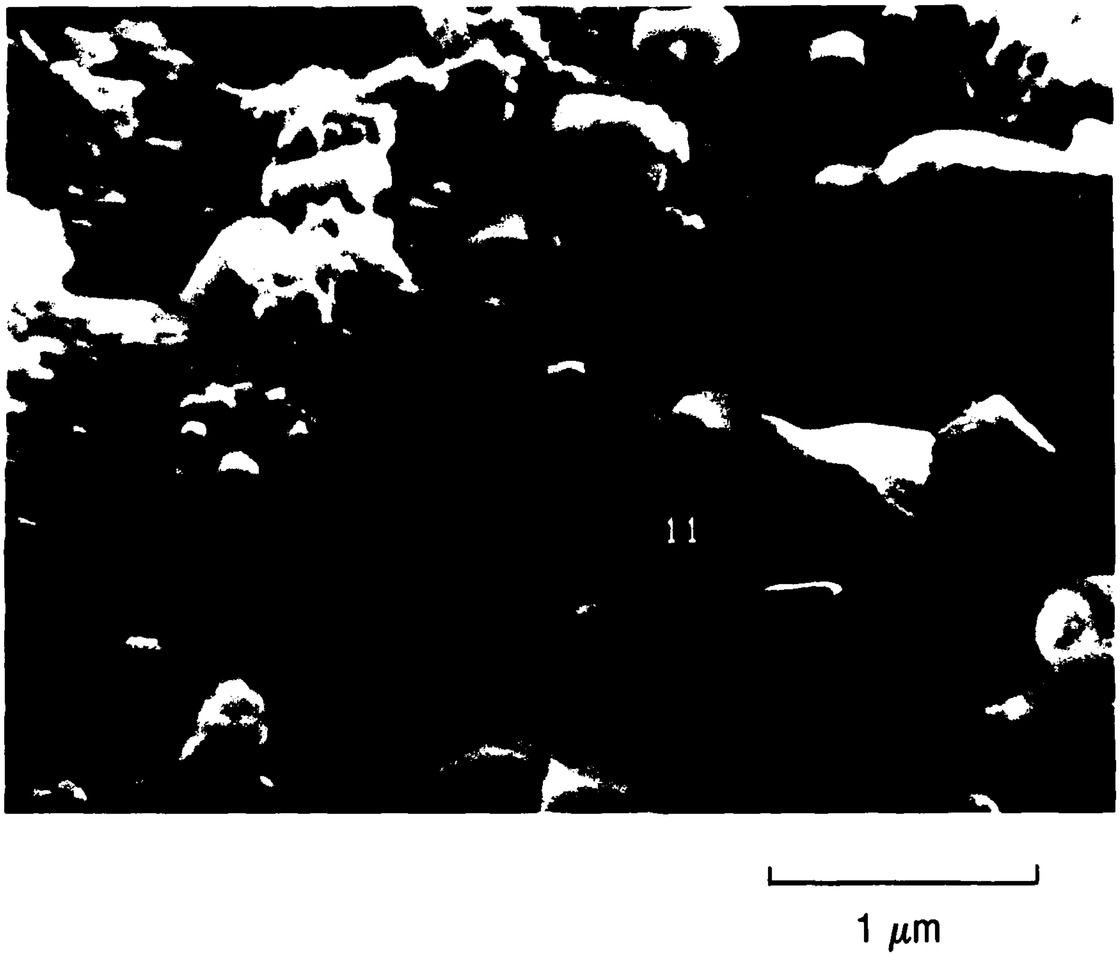

Fig. 4. Typical Region between Metal Crystallites Used for EDX Study of Heterojunction Interface

III. DISCUSSION AND CONCLUSION

EDX studies have been reported by Heiblum[1] on Ni/Au-Ge contacts. It was found that the surface of the annealed contacts was speckled with dark clusters. Braslau[6] has suggested that such nonuniformity is due to rapid etching of the GaAs surface by the molten Au-Ge alloy that is present during annealing. The EDX data showed that these clusters were rich in Ge and Ni. It was further found that the overall contact resistivity correlated with the clusters' size and density. This is the expected behavior, since these contacts are assumed to be ohmic by virtue of heavy n-type doping of the interface region by Ge.

The In/Pt contacts we reported do not show surface nonuniformity, except for that which is inherent in the evaporated In films. Although In melts well below the 500°C annealing temperatures used, the Pt layer reacts with the molten In and forms In_7Pt_3. This alloy melts at 894°C, and therefore does not permit excess molten In to contact the GaAs surface directly; hence a more uniform junction is created. The lower resistivity of the In/Pt contacts reported here, compared with others formed by thermal diffusion,[3] is probably due to the increased heterojunction area that results from the improved uniformity. This result is also consistent with the fact that these contacts have resistivities similar to those heterojunctions grown by MBE. The MBE contacts differ from ours in the grading distance and the degree of crystalline perfection. The details of how the heterojunction resistivity varies with the exact composition profile is being investigated, but is expected to be of secondary importance.

In conclusion, we have shown that In/Pt contacts to n-GaAs have an improved morphology compared with both Ni/Au-Ge and simple In/GaAs contacts. This improvement is thought to arise primarily from the use of a thin intervening layer of Pt. EDX and x-ray diffraction measurements are presented which show that a smooth, uniform graded heterojunction is formed in this system. These results are consistent with the observation that the resistivity of these contacts is similar to that observed in MBE-grown heterojunction ohmic contacts.

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